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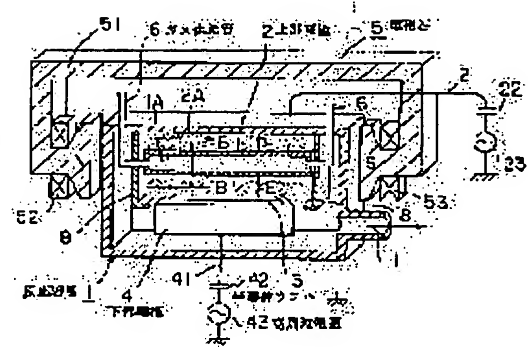
(71)Applicant : TOKYO ELECTRON LTD
(72)Inventor : TANAKA SUSUMU

(54) PLASMA PROCESSOR

(57)Abstract:
PURPOSE: To process a semiconductor wafer uniformly and besides at high speed by bringing homogeneous plasma into contact with the surface of a semiconductor wafer.
CONSTITUTION: This processor is equipped with a reactor 1, which forms vacuum space required for generation of plasma, an upper electrode 2, which is arranged above inside the reactor 1, a lower electrode 4, which is counterposed below the upper electrode 2 so as to oppose this and besides generates plasma by the vacuum discharge between it and the upper electrode 2 and doubles as a placing stage for a semiconductor wafer 3, and an electromagnet 5, which applies a magnetic field B orthogonal to the electric field between both these electrodes. This is so constituted as to form ring-shaped plasma, which surrounds the upper electrode 2 ranging over from the bottom to the top, by the magnetic field B applied by the electromagnet 5 and the electric fields made between each electrode 2 and 4, and also, bring this plasma into contact with the semiconductor wafer 3 on the lower electrode 4.



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Title:

Plasma processing apparatus

[Scope of the Claim for Patent]

[Claim 1]

A plasma processing apparatus comprising a processing container for forming a vacuum space necessary for generation of plasmas, an upper electrode disposed in an upper portion inside the processing container, a lower electrode serving also as a portion for placing a work disposed below and opposed to the upper electrode and generating plasmas by vacuum discharge between the lower electrode and the upper electrode, and a magnetic field application device for applying magnetic fields crossing electric fields between both of the electrodes, in which ring-shaped plasmas surrounding the upper electrode from the lower surface to the upper surface are formed by magnetic fields applied by the magnetic field application device and the electric fields applied between each of the electrodes, and the plasmas are brought into contact with the work on the lower electrode.

[Claim 2]

The plasma processing apparatus according to claim 1, wherein the direction of the magnetic fields is reversed

intermittently by controlling the magnetic field application device.

[Claim 3]

The plasma processing apparatus according to claim 1 or 2, wherein a lifting mechanism for lifting the upper electrode is disposed.

[Claim 4]

The plasma processing apparatus according to any one of claims 1 to 3, wherein a power supply is connected to the lower electrode and the voltage applied by the power supply to the electrode is made variable.

[Claim 5]

The plasma processing apparatus according to any one of claims 1 to 4, wherein a gas supply line for supplying a processing gas into the processing container is localized sideway of the upper surface of the processing container and the processing gas is supplied from the side of the upper electrode.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Use]

The present invention concerns a plasma processing apparatus.

[0002]

[Prior Art]

A plasma processing apparatus is an apparatus of conducting vacuum discharge in a processing container in which a processing gas is present to thereby generate plasmas and use them to apply predetermined processing to a work, and it has been utilized so far, for example, in a sputtering step, an ashing step, a CVD step, or an etching step of a semiconductor manufacturing process. On the other hand, since the interconnection structure has become multi-layered and refined more and more along with an increasing integration degree for semiconductors and the diameter of semiconductor wafers as the work has become larger in recent years, plasma processing which is uniform and conducted under a low pressure such as 30 mTorr has become a more important subject.

[0003]

In view of the above, in the existent plasma processing apparatus, for stably generating plasmas at a low pressure, a method has been adopted to confine plasmas to the periphery of electrodes by utilizing magnetic fields and conducting plasma

processing uniformly while increasing the density of the plasmas at the periphery thereof. Such existent art is described, for example, in JP-A Nos. Sho 59-140375 and Sho 61-86942. In the former, a wafer is placed on a magnetron electrode of a specific structure and plasmas are confined at the periphery thereof. In the latter, rotational magnetic fields are generated along the surface of the electrode and the behavior of electrons at the periphery of the electrode is restricted, so as to conduct plasma processing uniformly.

[0004]

[Subject to be Solved by the Invention]

However, in the existent plasma processing apparatus, while various attempts have been made for forming plasmas at high density to the periphery of the electrode as described above for conducting uniform plasma processing to a work at a low pressure, even such plasma processing apparatus still involves a problem that they are not yet satisfactory in view of uniform processing to cope with the trend of an increasing integration degree of semiconductors and increasing diameter of works.

[0005]

The present invention has been achieved for solving the problem as described above and intends to provide a plasma processing apparatus capable of applying plasma processing uniformly to a work by bringing homogeneous plasmas into contact

with the surface of the work at a low pressure.

[0006]

[Means for the Solution of Subject]

A plasma processing apparatus according to claim 1 of the present invention includes a processing container for forming a vacuum space necessary for generation of plasmas, an upper electrode disposed in an upper portion inside the processing container, a lower electrode also serving also as a portion for placing a work disposed below and opposed to the upper electrode and generating plasmas by vacuum discharge between the lower electrode and the upper electrode, and a magnetic field application device for applying magnetic fields crossing electric fields between both of the electrodes, in which ring-shaped plasmas surrounding the upper electrode from the lower surface to the upper surface are formed by magnetic fields applied by the magnetic field application device and the electric field applied between each of the electrodes, and the plasmas are brought into contact with the work on the lower electrode.

[0007]

In the plasma processing apparatus according to claim 2 of the invention, the direction of the magnetic fields is reversed intermittently by controlling the magnetic field application device in the invention described in Claim 1.

[0008]

In the plasma processing apparatus according to claim 3 of the invention, a lifting mechanism for lifting the upper electrode is disposed in the invention described in claim 1 or 2.

[0009]

In the plasma processing apparatus according to claim 4 of the invention, a power supply is connected to the lower electrode and the voltage applied by the power supply to the upper electrode by the power supply is made variable in the invention described in any one of claims 1 to 3.

[0010]

In a plasma processing apparatus according to claim 5 of the invention, a gas supply line for supplying a processing gas into the processing container is localized sideway of the upper surface of the processing container and the processing gas is supplied from the side of the upper electrode in the invention described in claims 1 and 2.

[0011]

[Function]

In the invention according to claim 1 of the present invention, when a processing gas is supplied into a processing container in a state where a work is placed on the lower electrode in the processing container to maintain a predetermined vacuum degree, and vacuum discharge is conducted in such a state between the upper electrode and the lower electrode, plasmas are

generated between both of the electrodes by the vacuum discharge, magnetic fields applied by the magnetic field application device cross the electric fields between both of the upper and lower electrodes, the crossing electromagnetic fields act on the plasmas to form ring-shaped plasmas turning around the upper electrode from the lower surface to the upper surface, and the plasmas turning around the upper electrode are in uniform contact with the work in the lower electrode, and the work can be put to uniform plasma processing.

[0012]

Further, according to the invention described in claim 2 of the invention, the magnetic pole of the magnetic field application device is reversed intermittently thereby capable of reversing the turning direction of the plasmas turning around the upper electrode intermittently to make the plasmas in uniform contact with the work.

[0013]

Further, according to the invention described in claim 3 of the invention, the distance between the upper electrode and the lower electrode can be set properly in accordance with the content of the plasma processing by lifting the upper electrode by the lifting mechanism.

[0014]

Further, according to the invention described in claim 4 of the invention, plasma processing optimal to the work can

be conducted by properly changing the application voltage to the electrode by the power supply depending on the kind of the work.

[0015]

Further, according to the invention described in claim 5 of the invention, the gas supply line is localized sideway to the upper surface of the processing container and a processing gas is supplied from the side of the upper electrode thereby capable of uniformly turning the plasmas around the upper electrode from the lower surface to the upper surface.

[0016]

[Example]

The present invention is to be described with reference to Examples shown in Fig. 1 to Fig. 4.

[0017]

As shown in Fig. 1, plasma processing apparatus in this embodiment is constituted such that the inside of a reactor 1 as a processing container, for example, applied with an alumite treatment to the surface of aluminum operates as an earth electrode 1A for plasma generation. Then, the plasma processing apparatus includes an upper electrode 2 disposed in a upper portion inside the reactor 1, a lower electrode 4 disposed in parallel below and opposed to the upper electrode 2, generating plasmas by vacuum discharge between the lower electrode and the upper electrode 2, and serving also as a portion

for placing a work, for example, a semiconductor wafer 3 horizontally, and an electromagnet 5 as a magnetic field application device as a magnetic field application device for applying magnetic fields B crossing electric fields E between both of the electrodes 2, 4 above the lower electrode 4. Further, the plasma processing apparatus is adapted to constitute ring-shaped plasmas surrounding the upper electrode 2 for the lower surface to the upper surface by the magnetic fields B applied by the electromagnet 5 and the electric fields E applied between both of the electrodes 2, 4, and bring the plasmas into contact with the semiconductor wafer 3 on the lower electrode 4.

[0018]

Referring more specifically to the plasma processing apparatus, plural gas supply lines 6 are disposed on both right and left edges at the upper surface of the reactor 1 used for supplying a processing gas (for example, chlorine type gas such as chlorine, fluorine type gas such as trifluoromethane) and an inert gas such as argon each individually or as a mixture into an evacuated reactor 1 passing therethrough, for example, in right to left symmetry such that the processing gas is supplied to the inside of the reactor 1 by the gas supply lines 6 to conduct plasma processing on the semiconductor wafer 2. Further, a discharge port 11 for the discharging a gas after plasma processing is formed to the lateral surface of the reactor

1.

[0019]

Further, the upper electrode 2 disposed in the reactor 1 is formed of an electrode material such as aluminum into a flat box-like rectangular shape and connected by way of a wiring 21 to a block capacitor 22 and a high frequency power supply 23. Then, the gas supply lines 6 penetrating the reactor 1 from the outside to the inside thereof are connected respectively at flanges 6A thereof to both of the right and left lateral surfaces of the upper electrode 2, for example, by way of insulating materials 24 of ceramics such as alumina by means of clamping members such as bolts 25 (refer to Fig. 2). Further, plural holes 2A are formed to the lower surface of the upper electrode 2 such that the processing gas introduced from both lateral surfaces of the upper electrode 2 by the gas supply lines 6 is jetted uniformly downward from the plural holes 2A and dispersed for a wide range in the reactor 1. Further, the electrode 2 is connected, for example, as shown in Fig. 2, by way of the gas supply line 6 to a lifting mechanism 7 having a motor 71, and moves vertically in the reactor 1 being driven by a motor 71 of the lifting mechanism 7 in the direction of an arrow such that the distance between the lower electrode and the upper electrode 4 can be properly set in accordance with the content of the plasma processing.

[0020]

On the other hand, the lower electrode 4 disposed below the upper electrode 2 is formed of an electrode material such as aluminum and integrated at the lower surface thereof with a cooling device (not illustrated) through which coolants such as liquefied nitrogen circulates. Further, the upper electrode 4 is connected by way of a wiring 41 to a blocking capacitor 42 and a high frequency power supply 43 and, in addition, adapted such that the voltage applied to the electrode 4 can be properly controlled variably by a voltage control device (not illustrated) in accordance with the content of processing for the semiconductor wafer 3. Then, the electrode 4 is adapted to be self-biased negatively by the blocking capacitor 42 upon generation of plasmas in a state where a high frequency voltage is applied. Although not illustrated, a matching circuit is connected with the electrode 4 and the applied voltage to the lower electrode 4 is stabilized by the matching circuit.

[0021]

Further, as shown in Fig. 1, the electromagnet 5 disposed to the outside of the reactor 1 has a gate type yoke 51 formed of a magnetic material (such as a yoke), and coils 52, 53 attached to both ends of the yoke 51 and forms an N-pole at the coils 52 and an S-pole at the coils 53. Then, in the electromagnet 5, the yoke 51 traverses the center in the direction of the depth above the reactor 1 rightward and leftward with the N-pole being situated on the left of the reactor 1 and the S-pole being

situated on the right of the reactor 1. Accordingly, the electromagnet 5 is constituted such that it can apply, when energized, magnetic fields B directing horizontally from the left to the right inside the reactor 1, that is, can apply the magnetic fields B in parallel with the plane of each electrode 2, 4. Further, the electromagnet 5 is constituted such that the current flowing direction is switched by a control device not illustrated to intermittently reverse respective polarities and intermittently reverse the direction of the magnetic fields B.

[0022]

Thus, the magnetic fields B cross the electric fields E applied between each of the electrodes 2, 4 upon applying a high frequency voltage to both of the upper and lower electrodes 2, 4 in the upper and lower portions respectively and induce $E \times B$ drift motion to electrons and ion particles in the plasmas generated between both of the electrodes 2, 4 by the electromagnetic fields, to turn the plasmas around the direction of arrow shown in Fig. 3 by the crossing electromagnetic fields and generate plasmas surrounding the upper electrode 2 in a ring-shape from the lower surface to the upper surface and in contact with the lower electrode 4 on the side of the lower surface of the upper electrode 2. Further, since the upper surface of the upper electrode 2 has a much larger area than the lower surface formed with plural holes 2A, intense plasmas

at high density are formed between the upper surface and the reactor 1. Then, the magnetic fields B are reversed intermittently as described above to reverse the moving direction of the electrons and the ion particles in the plasmas intermittently thereby capable of making the distribution state of the electrons and the ion particles uniform in the plasmas.

[0023]

Further, on both right and left lateral surfaces of the upper electrode 2, plasma shielding plates 8, 8 formed, for example, of an insulating material of ceramics such as alumina are opposed respectively each by way of a gap such that the plasmas are not diffused rightward and leftward of the electrodes 2, 4 by both of the plasma shielding plates 8, 8. The plasma shielding plate 8 is formed with a longitudinal recess (not illustrated) for passing the gas supply line 6 upon elevation of the upper electrode 2.

[0024]

Then, description is to be made to the etching operation by using the plasma processing apparatus described above. At first, an opening/closing mechanism not illustrated for the reactor 1 is opened and a semiconductor wafer 3 is entered from a preliminary vacuum chamber by using an unillustrated conveying mechanism. Then, the semiconductor wafer 3 is placed on the upper surface of the electrode 4. Then, the opening/closing mechanism is operated to seal the reactor 1 to render the inside

in a sealed state and forms a predetermined vacuum state in the inside.

[0025]

Then, the upper electrode 2 is lowered by the lifting mechanism 7 and a chlorine gas is supplied, for example, as an etching gas from the gas supply line 6 of the reactor 1 while setting the gap between the lower surface of the upper electrode 2 and the lower electrode 4, for example, to about 10 mm, and the gas pressure is controlled, for example, to 10^{-2} Torr. In parallel therewith, a high frequency voltage is applied to the upper electrode 2 and the lower electrode 4 by the high frequency power supplies 23, 43, and the electromagnet 5 is energized to apply magnetic fields being directed at first from the left to the right in the reactor 1.

[0026]

As a result of the operation described above, glow discharge is generated between both of the electrodes 2, 4 in the upper and lower portions, which generate plasmas of the chlorine gas between both of the electrodes 2, 4 and crossing electromagnetic fields are formed in the plasma region by the electric fields E and the magnetic fields B crossing thereto between both of the electrodes 2, 4. The electromagnetic fields induce $E \times B$ drift motion to the electrons and the ion particles in the plasmas to cause toroidal coil motion in the direction of the arrow in Fig. 3 so as to surround the periphery of the

upper electrode 2, which particularly promotes non-elastic collision between the electrons and chlorine molecules to increase the electrons and the ions in the plasmas thereby forming high density plasmas surrounding the periphery of the upper electrode 2 in a ring-shape by the plasmas and in contact with the lower electrode 4 and the semiconductor wafer 3. Further, the flowing direction of the plasmas is reversed in the direction opposite to the arrow shown in Fig. 3 by the intermittent reversal of the polarity of the electromagnet 5 to unify the plasmas. In this case, since the gas supply lines, etc. are not present on both upper and lower surfaces of the upper electrode 2, the E × B drift motion of the electrons and the ion particles is not hindered to unify the plasmas smoothly.

[0027]

Then, the unified plasmas are in contact with the surface of the semiconductor wafer 3 below the upper electrode 2 to form an ion sheath between the plasma region and the surface of the semiconductor wafer 3. The electrons in the plasmas reach the surface of the semiconductor wafer and are charged negatively in a self-biased manner prior to the ion particles in the ion sheath to cause a large potential difference between the plasma voltage and the self bias voltage of the semiconductor wafer 3. Due to the potential difference, ions in the plasmas fly the ion sheath at a high speed and collides vertically against the surface of the semiconductor wafer 3 to conduct anisotropic

reactive ion etching in accordance, for example, with the exposed pattern of silicon in the semiconductor wafer 3. In this case, since the ions in the plasmas are distributed uniformly over the entire surface of the semiconductor waver 3, the surface of the semiconductor wafer 3 is uniformly etched by the ions to form a silicon tetrachloride gas. The gas formed as a result of the etching is discharged from the discharge port 12 to the outside.

[0028]

As has been described above according to this embodiment, in a case where plasmas are generated between the upper electrode 3 and the lower electrode 4, magnetic fields B caused by the electromagnet 5 exert vertically to the electric fields E between both of the electrodes 2, 4 and the crossing electromagnetic fields form ring-shaped plasmas that turn around the upper electrode 2 from the lower surface to the upper surface to make the density of the plasmas higher and reverse the turning direction of the plasmas by the intermittent change of the direction of the magnetic fields B to unify the plasmas, and anisotropic etching can be conducted uniformly over the entire surface of the semiconductor wafer 3 by bringing the unified plasmas into contact with the semiconductor wafer 3.

[0029]

Further, Fig. 4 is a view showing another embodiment of the invention. This embodiment is constituted like in the

embodiment described previously except for forming the upper electrode 20 and the lower electrode (not illustrated) each in a circular planar shape and forming plasma shielding plates 80 for preventing the diffusion of plasmas generated between both of the electrodes 2, 4 into an arcuate shape conforming the shape of each of the electrodes 2, 4. Accordingly, the same function and effect can be expected as those in the embodiment described previously also in this embodiment.

[0030]

While a description has been made in this embodiment of a case where the polarity of the electromagnet 5 is reversed intermittently, each of the polarities may not always be reversed.

[0031]

Further, while the description has been made for the embodiment that the upper electrode 2 is lifted by the lifting mechanism 7, the lower electrode 4, instead, may be lifted.

[0032]

Further, while a description has been made in this embodiment described previously of a case having a high frequency power supply 43 for applying a voltage to the lower electrode 4, the high frequency power supply 43 may not always be necessary. Also in this case, the lower electrode 4 is self-biased undergoing the collision of the electrons in the plasmas to conduct the same anisotropic etching as described above.

[0033]

Further, in the embodiment described, while a description has been made only of the plasma processing apparatus used for reactive ion etching, the plasma processing apparatus according to the invention is applicable in the same manner also to other plasma processing apparatuses such as ashing, CVD, sputtering, etc.

[0034]

[Effect of the Invention]

As has been described above, according to the invention described in any one of claims 1 to 5 for the invention, it is possible to provide a plasma processing apparatus capable of bringing uniform plasmas into contact with the surface of the work and applying uniform plasma processing to the work.

[Brief Description of the Drawings]

[Fig. 1] A cross sectional perspective view showing the constitution for a main portion of an embodiment of a plasma processing apparatus according to the invention.

[Fig. 2] A cross sectional view showing a relation between a gas supply line and a lifting mechanism for an upper electrode of the plasma processing apparatus shown in Fig. 1.

[Fig. 3] An explanatory view for explaining behavior of plasmas in the reactor of the plasma processing apparatus shown in Fig. 1.

[Fig. 4] A view corresponding to Fig. 1 showing another

embodiment of the plasma processing apparatus according to the invention.

[Description of the References]

1 reactor (processing container)

2 upper electrode

3 semiconductor wafer (work)

4 lower electrode

5 electromagnet (magnetic field application device)

7 lifting mechanism

Fig. 1 【図1】

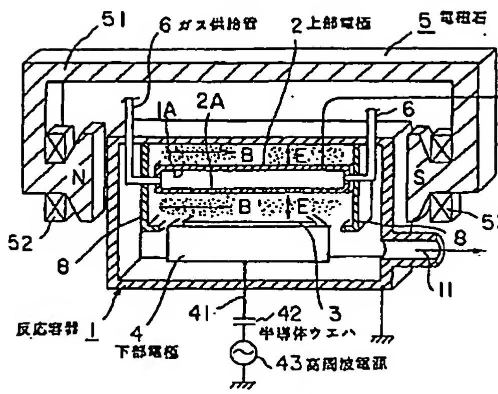


Fig. 2 【図2】

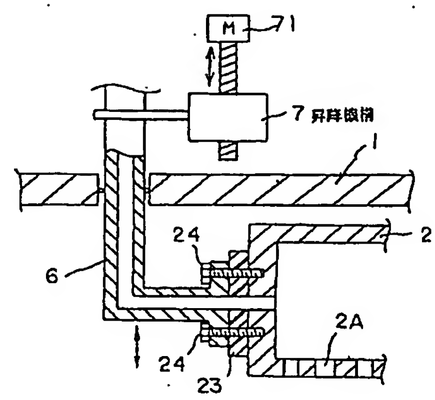


Fig. 3 【図3】

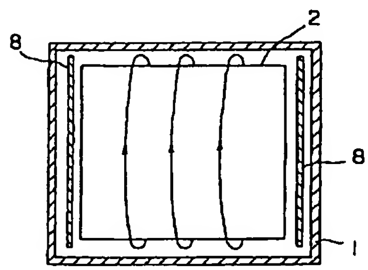
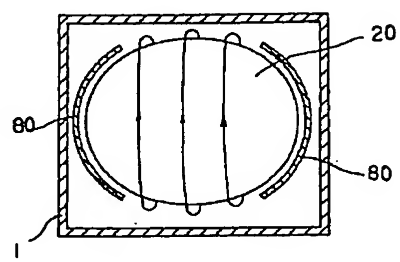


Fig. 4 【図4】



1 reactor (processing container)

2 upper electrode

3 semiconductor wafer (work)

4 lower electrode

5 electromagnet (magnetic field application device)

7 lifting mechanism

43 high frequency power supply